GENESIS OF CERTAIN ADIRONDACK GARNET DEPOSITS

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INTRODUCTION

The garnet-rich deposits discussed in this paper occur in northwestern Warren County, New York, and adjacent regions. The most important localities are shown on the accompanying geologic map. Garnets have been mined for abrasive purposes at a number of these places, but only the Barton Mine was active in 1937. The garnets of these localities are essentially the real almandite variety with some admixture of calcium and magnesium. Many of them have gem-stone color and translucency, but their highly fractured nature renders them largely unfit for jewelry.

There are various modes of occurrence of garnets in the Adirondack region. This paper is concerned only with those which occur (1) as numerous variably distinct dodecahedral crystals, generally from one-half to two inches in diameter, without envelopes of hornblende crystals, and irregularly scattered through a dioritic matrix, and (2) as numerous, generally rounded masses, from an inch to a foot or more in diameter, each surrounded by a distinct envelope of hornblende crystals, and irregularly embedded in long, lens-like bodies of dark gray gabbro-dioritic rock.

The problem of the origin of these garnets is a puzzling one. Twenty-five years ago the writer advocated a theory[1] according to which the garnets were produced by the action of quartz syenite magma upon lens-like inclusions of basic Grenville gneiss. Certain of the descriptive details then given are not here repeated. In the light of knowledge gained through later detailed field and laboratory work, including a visit to the region in 1937, the ideas set forth in the 1912 paper should be amplified and modified in certain important respects.

ROCKS OF THE REGION

The rocks of the region represent nearly all of the common types of Adirondack pre-Cambrian rocks. These are, in order of age, the Grenville metasediments, including crystalline limestone, quartzite and various schists and gneisses; gabbro and its metagabbro facies; anorthosite and its gabbroid facies; and the syenite-granite series. There are also more or less intimate mixtures of two or more of the various forma-

[1] Miller, W. J., *Econ. Geol.*, vol. 7, pp. 493-501, 1912.

tions, including injection, digestion, or assimilation of Grenville and metagabbro by both anorthosite and syenite-granite, and digestion or assimilation of anorthosite by syenite-granite.

Garnets without Hornblende Envelopes

It is suggested that the garnets without hornblende envelopes were produced where anorthosite magma reacted with or assimilated metagabbro inclusions. Selected localities, where this theory may be tested will now be discussed.

Hooper Mine. This mine is situated about a mile east of the northern part of Thirteenth Lake (see map). It has been a large producer of garnets. In the extensively mined rock the garnets occur in the form of dodecahedral crystals, often with fairly good faces. The garnets range in size up to more than an inch in diameter. They are rather thickly scattered through a medium to moderately coarse grained, dark to light gray, gneissoid rock of a general dioritic appearance. The matrix varies a good deal in degree of foliation and in composition. All of the garnets are highly fractured. They are not enveloped in hornblende crystals as are the garnets in certain other localities. In the richer zones the larger garnets are seldom more than 1 or 2 inches apart.

Thin sections of the matrix of the very common garnet-rich, darker gray medium grained rock show the following volume percentages of minerals: andesine, 60 to 65; hornblende, 30 to 35; a little enstatite and biotite; and very little pyrite. Hand specimens contain 10 to 20 per cent of garnet. The rock has, therefore, the composition of a garnet-rich diorite. A less common facies of the garnet-rich rock is similar to that just described, but it is lighter gray, and contains 10 to 15 per cent of biotite, largely altered to chlorite. Another, still less common, facies of the mine rock is somewhat finer grained and more uniform in appearance. It is greenish gray, and the scattering garnets are much smaller than usual. A thin section shows volume percentages of minerals as follows: oligoclase-andesine, 95; garnet, 3; magnetite, 1; and a little monoclinic green pyroxene and apatite. This rock, is therefore, an anorthosite in composition.

The above described facies of the garnet-rich mine rock shows a crudely developed zonal or banded structure in and about the extensive mine pits, but the zones are usually not noticeable except on rather close inspection of the exposures. The crude banding is accentuated by the distribution of the mafic minerals in roughly defined zones an inch or two wide, parallel to the foliation.

In an older mine pit, north of the main openings, the rock is much like the usual mine rock, but it includes a crude band of dark hornblende-

rich rock containing numerous small garnets. This band ranges up to 10 feet wide, and it lies parallel to the foliation of the mine rock. Its indefinite borders are plainly involved with, and more or less merge into, the usual anorthositic or dioritic garnetiferous material. This dark band represents part of an older rock (metagabbro), which was relatively little affected by the intrusion of the anorthosite magma in this vicinity.

An area of anorthosite, varying to anorthosite-gabbro, surrounds the garnet-rich mine rock (see map). Close to the mine, some of this rock might easily be mistaken for a basic facies of the syenite. It is, however, a greenish gray, medium grained anorthosite consisting of 93 to 95 per cent of oligoclase-andesine, together with some scattered garnet, monoclinic pyroxene, magnetite and apatite. It is notably granulated.

Along the southeastern side of the Hooper Mine area much of the rock is a medium to fine grained, highly granulated anorthosite containing some small scattered cores of dark bluish gray plagioclase crystals.

Much of the rock in the northeastern part of the area is medium to fine grained, crudely foliated, gabbroic anorthosite. A thin section shows the following approximate volume percentages: plagioclase (mainly andesine), 84; hypersthene, 10; hornblende, 3; magnetite 3; and a little pyrite and apatite. A few small garnets occur in the hand specimens. It is important to note not only that this rock, on the one hand, merges into the garnet-rich mine rock but also, on the other hand, into the large body of syenite in this part of this general region.

In view of the above statements, the following explanation of the origin of the garnets is suggested. A large lens-like inclusion or possibly several smaller inclusions, of metagabbro (not basic Grenville as formerly supposed) was caught in the invading anorthosite magma, cut to pieces, and variably digested or assimilated by the magma. The resulting product is the crudely foliated dioritic mine rock with its numerous large garnets scattered through the mass. The material of the garnets was produced by the reaction between the anorthosite magma and the metagabbro, and conditions in the cooling syntectic magma were favorable for the growth of the large variably euhedral garnets. The anorthosite of the area surrounding the mine rock was probably rendered irregularly basic by digestion of variable and smaller amounts of metagabbro.

Next came the intrusion of the syenite magma which more or less thoroughly digested or assimilated the borders of the body of variably impure anorthosite which surrounds the mine rock. This hypothesis explains not only the crude banding and variable composition of both

the mine rock and that of the immediately surrounding anorthosite and gabbroic anorthosite, but also the lack of anything like sharp boundaries betwen the mine rock and the anorthosite on one hand, and the anorthosite and the syenite on the other.

Ruby Mountain areas. Two areas on the south face of Ruby Mountain present some interesting phenomena which throw light upon the problem of the origin of the Hooper Mine garnets. Garnets have not been mined in these areas. The two lens-like masses, variably rich in garnets, lie within a body of typical, moderately foliated, Adirondack syenite, and they follow the general structural trend of this locality. Much of the rock of the more southerly lens has the general composition of hornblende diorite, rich in garnets, and with something of an anorthositic appearance. These garnets, ranging commonly from half an inch to three inches in diameter, do not have hornblende envelopes. The garnet-bearing rock varies considerably in the form of streaks and crude bands parallel to the foliation. Some of these streaks or bands consist of nearly pure hornblende without sharp boundaries against the main body of the rock. The main body of the rock shows hornblendes of all sizes to almost an inch long irregularly scattered through the mass singly and in groups. Much of the rock of this lens is, however, like that of the Hooper garnet mine already described. Fine exposures in the bed of the brook in the western part of the area show the rock to be much like that just described, but it is not as rich in garnets, and one facies looks like a fine to medium grained, greenish-gray, crudely foliated, moderately hornblendic anorthosite through which is scattered a sprinkling of small garnets.

The more northerly mapped lens or area is still richer in hornblende and more foliated in general, and the garnets are smaller. Some outcrops taken individually may be classified as metagabbro.

The evidence leads to the conclusion that the rocks of these lenses represent an irregular mixture which resulted from more or less intimate cutting and digestion of metagabbro by anorthosite magma, and that the lenses in turn are inclusions in the syenite against which there are no sharp contacts because of some assimilation of borders of the inclusions by the syenite. As supporting evidence for this hypothesis, a boulder in a field in this vicinity, one-sixth of a mile north of the outlet of Thirteenth Lake, may be described briefly. This is a glacial boulder, 8 feet in diameter. A considerable portion of it consists of typical anorthosite carrying an inclusion (5 feet long) of dark, fine to medium grained hornblende-garnet gneiss, probably altered metagabbro. The inclusion has been partly cut and injected by the anorthosite. Much of

the boulder is crudely foliated, medium to moderately coarse grained hornblende-garnet-plagioclase rock which quite clearly has resulted from digestion or assimilation of the old dark rock (probably metagabbro) by the anorthosite. The last named facies varies considerably in amounts of hornblende and garnet, as well as in degree and regularity of foliation. Within a foot or two of the inclusion, some hornblendic material is irregularly streaked through anorthosite.

Roaring Brook area. A little area of garnet-rich rock is shown on the geologic map at the eastern end of the area of the anorthosite on the north slope of Gore Mountain. There are excellent exposures in the bed of Roaring Brook, but the exact size of the area is not known. The garnet-rich rock lies parallel to the foliation of the syenite which partly surrounds it. The rock is almost exactly like very common facies of the Hooper Mine garnet-rich rock, and much like that of the Ruby Mountain lenses described above. The garnets range from half an inch to $1\frac{1}{2}$ inches in diameter, some of them with crude suggestions of hornblende envelopes. The nature and relations of this garnet-rich rock strongly suggest that it originated in the same manner as the Hooper Mine rock and the garnetiferous lenses on Ruby Mountain.

A narrow band, much like the Hooper Mine rock, lies between the mine rock and the syenite at the Barton Mine locality. It is described and explained beyond under the caption "Barton Mine."

Garnets with Hornlende Rims

It is suggested that the garnets with conspicuous hornblende envelopes were produced by dynamo-thermal action of quartz syenite magma upon border portions of gabbro bodies, and upon inclusions of it in the syenite, no anorthosite having been involved in their genesis. Evidence from several selected localities will now be presented in support of this hypothesis.

Barton Mine. This is the most interesting mineral locality within the region under consideration. The remarkably large garnets have been mined for many years. The mine is located about two-thirds of a mile north of the summit of Gore Mountain (see map).

The garnet-rich mine rock occurs as a long, narrow, lens-like mass about three-fourths of a mile long with a nearly east-west strike. Both the mine rock and the syenite upon which it rests on the south show a folation of 15° north.

The size of the garnets and their mode of occurrence in the mine rock are of unusual interest. The matrix or rock carrying the commercial garnets is a gray, medium grained, moderately foliated rock of gabbro-

dioritic composition with much andesine-labradorite and hornblende, together with some hypersthene and biotite, and small amounts of magnetite, apatite, and pyrite. Imbedded in this matrix are numerous, rounded, well scattered, brownish red garnets whose diameters are commonly 2 to 6 inches, and not rarely 1 or 2 feet. These garnets are always highly fractured, and small fragments are translucent. They rarely exhibit more than suggestions of dodecahedral crystal boundaries. A remarkable feature is the never failing occurrence of an envelope of pure, black, medium grained hornblende crystals completely enclosing each garnet. As a rule the envelopes increase in size with the size of the garnets, some of them being as much as 2 or 3 inches thick. Irregular nests of basic plagioclase, often associated with some augite and biotite, occur very locally between a garnet and its hornblende rim. These nests are usually from one-half of an inch to an inch or more across. This coarse crystalline plagioclase, which is remarkably clear, is about on the border between labradorite and bytownite.

The red garnets, each surrounded by a black rim, imbedded in the gray gabbroic matrix, present a striking appearance on the walls of the extensive mine pits.

A section across the strike of the garnet-rich mine rock, and extending from the syenite on the south to gabbro on the north (see map), shows a gradational series involving at least six zones. These changes occur within a distance of about 150 feet across the strike. The large body of rock constituting the mass of Gore Mountain just to the south of the mine is typical Adirondack, gneissoid, quartz syenite. Approaching the mine, the syenite becomes distinctly more basic and it contains a sprinkling of little garnets. Thin sections of this rock show volume percentages: oligoclase, 45 to 60; microperthite, 25 to 35; quartz, 1 to 8; hypersthene, 5 to 7; hornblende, 1 to 3; garnet, 2 to 3; magnetite, 1 to 2; apatite, 1; and usually a little diallage, pyrite, or zircon.

The syenite just described grades into a zone of somewhat variable garnet-bearing rock several yards wide, which is, in composition and structure, much like that of the most common Hooper Mine rock, and also like that of the lenses on Ruby Mountain and on Roaring Brook, all of which have been described. This crudely foliated rock contains, by approximate volume percentages: oligoclase-andesine, 60; very irregularly distributed hornblende, 30; scattering red garnets, 10. The garnets vary to nearly an inch in diameter. Many of them show crystal outlines, but they do not have hornblende rims. This zone has a distinctly dioritic composition.

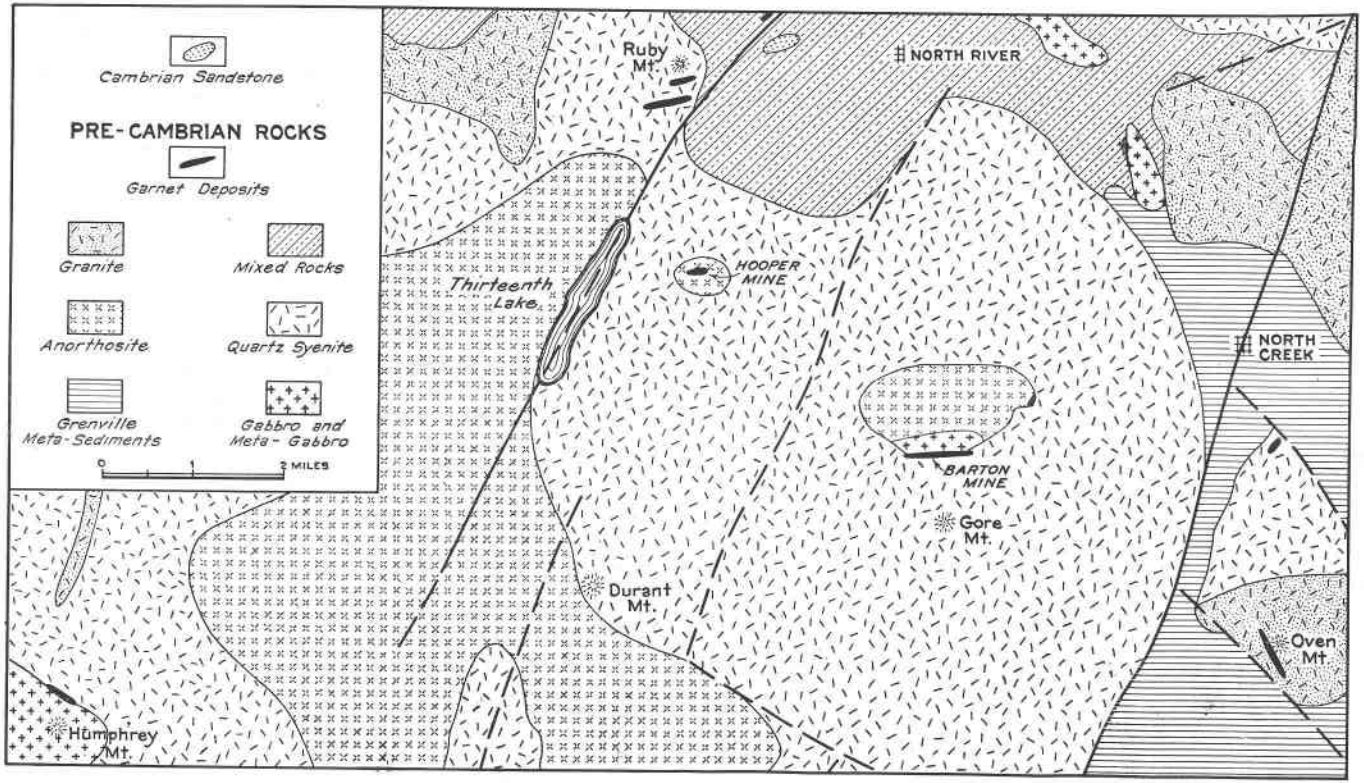

FIG. 1. Geologic map of the North Creek-Thirteenth Lake region in the Adirondack Mountains. Locations of important garnet deposits are shown.

The garnet-bearing rock just described grades through a zone 8 or 10 feet wide into the typical garnet-rich mine rock which, as above mentioned, has the composition of a hornblende-rich gabbro-diorite containing the large garnets, each with an envelope of hornblende crystals. This garnet-rich zone reaches a width of about 100 feet across the outcrop. Along its northern side the garnets are much smaller and the hornblende rims are indistinct.

The last mentioned zone grades through a few feet of hornblende-rich hypersthene gabbro, containing numerous tiny garnets, into the mapped body of true gabbro of the area just north of the mine. This gabbro is rich in labradorite, hypersthene, and tiny garnets, and it contains some biotite, hornblende, and olivine. It is a massive rock with a distinct ophitic texture.

The following hypothesis may be offered by way of explanation of the various zones just described. Before the intrusion of the syenite magma, the southern border portion of the body of gabbro (probably metagabbro) was more or less intimately cut and assimilated by the anorthosite magma, producing a syntectic rock rich in fairly large garnets without hornblende envelopes, and in a manner similar to origin of the already described Hooper mine rock. Then came the great intrusion of quartz syenite magma which, on the south, cut out all of the true anorthosite and variably digested or assimilated most of the then existing garnet-bearing syntectic rock, producing a new syntectic rock with numerous small garnets, and leaving a band of the older garnetiferous syntectic rock, a few yards wide, next to the mine. This explains both the garnetiferous basic facies of the syenite and the zone of dioritic rock (Hooper Mine type) containing fairly large garnets without hornblende envelopes.

By metamorphism, induced by the rise of the great body of quartz syenite magma, the mine rock, with its large hornblende-enveloped garnets, was produced along the southern side of the body of gabbro. The composition of the mine rock indicates that little if any material was added to the gabbro by the syenite magma, and so the nature of the metamorphism was largely or wholly dynamo-thermal, both pressure and heat having been supplied by the magma as it enveloped remnants (that is, the mapped bodies) of the once more extensive gabbro and anorthosite (see map). The destruction of the ophitic texture and the crude foliation of the mine rock are thus readily accounted for.

The matrix of the garnet-rich mine rock contains much hornblende, little hypersthene, and no olivine in contrast with the gabbro. The gabbro contains about as much garnet, in the form of numerous tiny grains without hornblende rims, as the mine rock with its large horn-

blende-enveloped individuals. It seems clear, therefore, that the mine rock is simply a more or less chemically and mechanically altered and recrystallized facies of the gabbro.

Relations between the gabbro and the anorthosite north of the Barton Mine are rather obscure because of the dense vegetation. No rock at all like the garnet-rich mine rock could be found bordering the gabbro on the north, but the southern portion of the anorthosite body contains some injected and partly digested, garnetiferous fragments of the metagabbro.

Old Hooper Mine. This mine, which has not been operated for many years, lies $1\frac{2}{3}$ miles west-northwest of North River (see map). The garnets occur in a lens of crudely foliated garnet-rich hornblende-plagioclase rock, quite certainly metagabbro. This lens of dark gneiss lies in grano-syenite parallel to the crude foliation of the latter. It shows a northwesterly dip of 25°. The very irregular contacts of the lens rock against the country rock are generally not sharp, and the borders of the lens are somewhat cut by the grano-syenite. A conspicuous zone in the lens is a gabbro-diorite carrying numerous irregularly scattered garnets, each of which has a rim of hornblende. This rock is almost exactly like the mine rock of the Barton Mine, but the garnets are smaller. A facies of the dark rock of the lens is a rather massive, medium to moderately coarse grained, dark gray, hornblende-rich rock (metagabbro) containing many red garnets which are usually from 1 to 5 millimeters in diameter. Another facies is a medium to fine grained, nearly black hornblende gneiss containing no garnets. Small amounts of biotite-hornblende-garnet schist also occur. These facies are by no means sharply separated from each other.

It seems clear that these garnets were developed by metamorphism of a small body of gabbro which was caught in the invading grano-syenite magma, and in a manner similar to the Barton Mine occurrence. The relations of the rocks on the mountainside above the mine support this view. There is no associated anorthosite.

Humphrey Mountain Mine. Some garnets have been mined on the northeastern face of Humphrey Mountain along the contact between the syenite and the gabbro of this locality (see map). The garnets, each with a rim of hornblende, occur in a dark gray, gabbro-dioritic rock in almost exactly the same manner as those in the Barton Mine. The garnet-rich material is quite certainly metagabbro which grades though a foliated facies into the typical massive gabbro of Humphrey Mountain. Close to the mine the foliated metagabbro is somewhat injected with syenite. There is no sign of any anorthosite. All evidence supports the

view that this garnet deposit was produced essentially by dynamo-thermal metamorphism of a border portion of the Humphrey Mountain gabbro by the invading quartz syenite magma.

Garnet deposits of adjoining quadrangles. Several other deposits in which numerous large red garnets with hornblende envelopes are embedded in dark gray metagabbro have been examined by the writer. One of these is on Oven Mountain in the North Creek quadrangle where a mine was operated many years ago. The garnet-bearing rock is large, distinct, lens-like inclusion of metagabbro (not Grenville as formerly supposed) in grano-syenite. Similar garnet-rich rock, with garnets up to 5 inches in diameter, occurs in the form of several small variably altered lens-like inclusions of metagabbro in gneissoid grano-syenite at the Rexford Mine, $1\frac{1}{4}$ miles south-southeast of North Creek. Prospect holes have been opened in a similar garnet-rich deposit half a mile east of Bull pond in the Newcomb quadrangle, and 2 miles southeast of Forest Home in the Blue Mountain quadrangle. Both of the last named deposits lie between syenite and gabbro. At the Crehore Mine on the face of Casey Mountain, in the Newcomb quadrangle, $3\frac{1}{2}$ miles northwest of North River, garnets with hornblende envelopes occur in a lens of amphibolite (metagabbro) in quartz syenite. Several mapped bodies of gabbro occur in the general vicinity.

All of the garnet deposits just described as occurring in adjoining quadrangles quite certainly resulted from metamorphism of border portions of gabbro by quartz syenite magma as in the cases of other similar deposits already explained. In none of these deposits is there any directly associated anorthosite.